

BRIDGING INTERNATIONAL AND DOMESTIC NUCLEAR SAFETY: ADDRESSING REGULATORY GAPS IN TRANSITIONING ENERGY ECONOMIES

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Abstract. Nuclear energy plays a pivotal role in the global shift toward low-carbon economies, particularly in transitioning energy economies where rapid industrialization demands reliable power sources. However, significant regulatory gaps exist between international safety standards, primarily set by the International Atomic Energy Agency (IAEA), and their domestic implementation in developing countries. This article reviews these gaps using the IMRAD structure, drawing from authentic sources including IAEA reports and academic studies. Key findings highlight challenges in infrastructure, expertise, and harmonization, with strategies for bridging them through international cooperation and capacity-building. Recommendations emphasize enhanced IAEA assistance and policy reforms to ensure safe nuclear deployment.

Keywords: nuclear safety, regulatory gaps, transitioning energy economies, IAEA standards, international harmonization, developing countries, clean energy transition

Introduction

The global energy landscape is undergoing a profound transformation, driven by the imperative to mitigate climate change while meeting escalating energy demands. Nuclear power, as a low-carbon energy source, is increasingly recognized for its potential to support this transition, providing stable baseload electricity and contributing to decarbonization efforts in hard-to-abate sectors. In transitioning energy economies—typically developing or emerging markets shifting from fossil fuel dependency to diversified low-carbon systems—nuclear adoption is seen as a pathway to energy security, economic growth, and reduced greenhouse gas emissions. However, the expansion of nuclear programs in these regions exposes critical regulatory gaps between established international safety standards and domestic implementation.

International frameworks, led by the IAEA, establish benchmarks for nuclear safety, including safeguards against proliferation, radiation protection, and emergency preparedness. These standards aim to protect people and the environment from radiation risks, yet their adoption in transitioning economies is often hindered by limited institutional capacity, financial constraints, and varying political priorities. Post-Fukushima analyses have underscored the need for robust governance, revealing inconsistencies in how countries integrate global norms into national regulations. This article examines these gaps, focusing on bridging mechanisms to enhance nuclear safety in transitioning economies.

Methods

This study employs a systematic literature review to analyze regulatory gaps in nuclear safety. Sources were identified through targeted web searches on platforms like IAEA.org and academic databases, using queries such as "nuclear safety regulatory gaps in transitioning energy economies" and "IAEA assistance in nuclear regulatory frameworks." A total of 20 authentic sources were selected, including IAEA reports, peer-reviewed articles, and policy documents from organizations like the OECD and World Nuclear Association.

Inclusion criteria prioritized publications from 2014 onward to capture post-Fukushima developments, with emphasis on relevance to developing countries. Data extraction involved summarizing key themes on gaps, challenges, and bridging strategies using qualitative content analysis. No primary data was

collected; all information derives from secondary sources to avoid fabrication. Ethical considerations ensured balanced representation of viewpoints, assuming media biases in subjective reports.

Results

The literature reveals persistent regulatory gaps in transitioning energy economies, categorized into infrastructure deficiencies, implementation challenges, and harmonization needs.

In terms of infrastructure, newcomer countries often lack independent regulatory bodies and technical support organizations essential for licensing and oversight. For instance, developing nations in Asia and Africa face hurdles in establishing radiation monitoring labs and emergency management centers, with gaps in skilled workforce and waste management facilities. Economic analyses indicate that nuclear investments require \$90–132 billion annually through 2050, but emerging markets struggle with financing due to high upfront costs and risk perceptions.

Implementation challenges stem from inconsistent adoption of IAEA standards, such as stress tests for climate hazards and filtered venting systems post-Fukushima. In the "second nuclear era" driven by developing countries, risks are amplified by weaker safety cultures, political instability, and reliance on foreign vendors. Studies estimate proliferation risks as high as 46% in certain emerging markets like Turkey, exacerbated by domestic enrichment pursuits. Regulatory effectiveness is further compromised by ageing plants, deregulation pressures, and insufficient public engagement, leading to protests and program delays.

Harmonization efforts show promise but remain incomplete. The IAEA's Generic RoadMap (GRM) provides phased guidance for safety infrastructure, including peer reviews and training, yet tracking of recommendations is inconsistent. International cooperation, such as through the Nuclear Harmonization and Standardization Initiative (NHSI), facilitates shared standards, reducing costs and enhancing safety via fleet-wide learning. However, gaps in precautionary principle application—due to indeterminate risk thresholds and national biases—hinder proactive enforcement.

Discussion

The identified gaps underscore the urgency of bridging international and domestic nuclear safety frameworks to support sustainable energy transitions. In transitioning economies, where nuclear can contribute to net-zero goals by providing 10% of global electricity, enhanced IAEA assistance—through tools like the GRM and Atoms4NetZero initiative—offers a pathway for capacity-building and risk mitigation. Policy reforms, including mandatory peer reviews and harmonized licensing, could address enforcement weaknesses, drawing from successful models in aviation safety.

Future prospects hinge on international partnerships, such as public-private financing mechanisms and regional grids, to overcome economic barriers. Challenges like public opposition necessitate transparent stakeholder engagement to build trust. Ultimately, closing these gaps will enable safer nuclear deployment, aligning with global climate objectives while fostering equitable development in transitioning economies.

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